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MEASURING WATER IN IRRIGATION CHANNELS

VARIOUS TYPES of weirs have long been employed for measuring the quantity of water flowing in irrigation channels. The Parshall measuring flume has only recently been developed.

The weirs in most common use are of the rectangular, Cipolletti, and 90° triangular-notch types. Weirs have the advantage of being easy to construct and operate. Their disadvantages are that they can not be installed in channels having slight fall, and the accumulation of silt above the weir notch may necessitate frequent cleaning and may render the device more or less inaccurate.

The Parshall measuring flume is more difficult to construct and install correctly, but it will measure water accurately in channels carrying silt or having comparatively slight fall.

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MEASURING WATER IN IRRIGATION CHANNELS[1]

By R. L. PARSHALL, *Senior Irrigation Engineer, Division of Irrigation, Bureau of Agricultural Engineering*

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INTRODUCTION

THE CHIEF OBJECT of accurately measuring irrigation water is its equitable distribution, both at the point of diversion and at other points, but when accurate measurement is employed it almost invariably results also in reducing waste, making possible the extension of the use of water to some to whom it previously had been denied because of its apparent scarcity. The purpose of this bulletin is to encourage and assist in the use of more accurate methods of measuring water flowing in open irrigation channels. It is not practicable to cover all methods which are employed, and this bulletin is therefore limited to descriptions of approved devices now in general use.

WEIRS

The weir is the simplest and most accurate of all of the more practical devices commonly used to measure water for irrigation purposes. In its simplest form it consists of a bulkhead having in its top an opening of fixed dimensions and shape for the passage of water. The opening is called the weir notch, its bottom edge the crest, and the depth of water passing over the crest the head. The horizontal distances from the ends of the crest to the sides of the weir box are called end contractions, and the vertical distance from the crest to the floor of the weir box or channel is the bottom contraction. When these distances are great enough to cause water to pond above the weir, so that it approaches the weir notch at a low velocity, the weir is said to have complete contractions. To create this condition the banks or sides of the channel upstream from the bulkhead must be distant from the end of the weir notch at least twice the maximum depth of water on the weir crest, the bottom of the channel must be lower than the weir crest by at least three times that maximum depth, and the velocity of approach must not exceed about 0.3 foot per second.

For proper operation of completely contracted weirs the channel upstream from the weir must be large enough to insure adequate stilling of the water. The stilling basin above the weir is called the

[1] Prepared under the direction of W. W. McLaughlin, Chief, Division of Irrigation, Bureau of Agricultural Engineering, and in cooperation with the Colorado Agricultural Experiment Station.

weir box or weir pond. The sheet of water passing through the notch and falling over the weir is termed the "nappe." When the downstream water surface is far enough below the crest that air has free access under the nappe, the flow is said to be free; otherwise it is submerged.

Three weir types are considered in this bulletin: (1) The rectangular weir, of which the weir notch has a level crest and vertical sides; (2) the Cipolletti, or trapezoidal weir, with level crest but

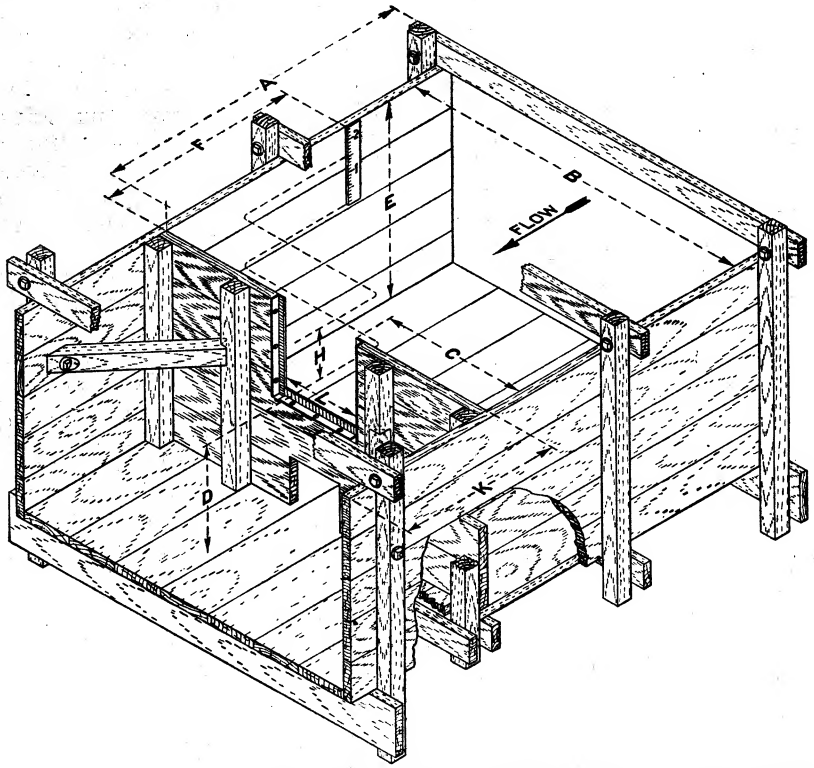

FIGURE 1.—Weir box with rectangular weir notch formed by angle-iron crest and sides

with the sides of the notch inclined outward from the vertical at slopes of 1 unit horizontally to 4 units vertically; (3) the 90° triangular-notch weir, formed by side slopes which are 45° from the vertical, meeting in a point.

CONSTRUCTION AND SETTING

The crest and sides of a weir notch should be straight and their edges should not be more than one-eighth of an inch thick. The crest of a rectangular or Cipolletti weir should be level, and the sides should make exactly the proper angles with the crest. The sides of the triangular-notch weir should make 45° angles with a vertical line. A head of 0.1 foot over the crest is enough to permit the stream to clear the downstream edges of the crest and sides. For temporary use, a piece of stiff sheet metal cut in a semicircle approximately the shape of the cross section of the channel and somewhat larger with a weir

notch cut in the top edge may serve for making rough measurements of small discharges. Such a device is called a portable weir. In setting this type of weir it is only necessary to force the metal plate firmly into the bottom and sides of the channel and then level the crest.

If a more permanent structure is desired, a wooden bulkhead properly supported by end posts and set well into the sides and bottom of the ditch may be built across the channel. The weir notch is cut into the top of this bulkhead. Experience has indicated that where the notch is made with crest and sides of wood, the edges may split, crack, or be crushed, causing irregularities and unsatisfactory measurements. It is better practice to cut a rectangular notch opening with a crest 3 inches longer than required, and use 1½ by 1½ by ⅛ inch angle iron for the finished crest and sides, as shown in Figure 1. The side pieces for such a rectangular weir should first be temporarily set and the crest piece firmly set between them. A carpenter's square and level may be used in finally determining the proper position of the vertical pieces. Heavy screws should be used to hold the pieces in place.

It is somewhat difficult to construct a weir of the Cipolletti type, using angle iron for the crest and sides of the notch, because of the angle made by the sides. For this reason it is perhaps better to cut the notch in a sheet of stiff metal and fasten the sheet to the inside face of the bulkhead, cutting the notch in the bulkhead 2 inches oversize in order not to interfere with the nappe. One objection to the Cipolletti type of weir, if only a bulkhead is constructed, is the difficulty of maintaining ample side and bottom contraction distances. To overcome this difficulty the bulkhead may be built inside a wood or concrete structure such as is shown in Figure 1. Dimensions of such a structure, for the rectangular, Cipolletti, or 90° triangular notch weir, are given in Table 1. The letters at the heads of the columns in Table 1 are intended to aid in identifying the various parts of the structure shown in Figure 1.

TABLE 1.—*Weir-box dimensions for rectangular, Cipolletti, and 90° triangular-notch weirs*

(The letters at the top of the box heads refer to Figure 1)

RECTANGULAR AND CIPOLLETTI WEIRS

Discharge	H Maximum head	L Length of weir crest	A Length of box above weir notch	K Length of box below weir notch	B Total width of box	E [1] Total depth of box	C End of crest to side of box	D Crest to bottom of box	F Gauge distance
Sec.-ft.	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
½ to 3	1.0	1	6	2	5½	3½	2¼	2	4
2 to 5	1.1	.1½	7	3	7	4	2¾	2⅓	4½
4 to 8	1.2	2	8	4	8½	4½	3¼	2¾	5
6 to 14	1.3	3	9	5	12	5	4½	3¼	5½
10 to 22	1.5	4	10	6	14	5½	5	3½	6
90° TRIANGULAR-NOTCH WEIR									
½ to 2¼	1.00	---	6	2	5	3	2½	1½	4
2 to 4⅓	1.25	---	6½	8½	6½	3¼	3¼	1½	5

[1] This distance allows for about 6 inches freeboard above highest water level in weir box.

The weir box should be set in a straight section of the channel, with the floor level in both directions and the side walls vertical. To prevent undermining or washing around the structure, cut-off walls should be provided at both ends and the back filling tamped in place. If the bulkhead is set upstream from the lower end of the structure, a portion of the floor downstream from the bulkhead will serve to prevent erosion of the bottom of the channel. The banks and bottom of the channel for 15 to 20 feet upstream from the weir box should be trimmed to conform approximately to the cross section of the box.

One of the main difficulties in the use of weirs is the accumulation of deposits in the weir box. Hand cleaning by means of a shovel or by team and scraper where convenient, is frequently necessary to maintain proper contraction distances. For cleaning the weir box, an opening of sufficient size through which the deposits may be sluiced out and passed on down the channel, may be provided in the bulkhead at the floor line beneath the weir notch. (Fig. 1.) A removable gate or cover should be provided for this opening and securely fixed in place when the weir is in operation.

MEASUREMENT

The discharge in cubic feet per second over the weir crest is determined directly by the depth or head (H) in feet, and the length of crest (L) in feet. As the water passes through the weir notch, its surface curves downward. This curved surface, or drawdown extends upstream a short distance from the weir notch. The head should be determined at a point in the quiet water above this drawdown. For general practice, the distance upstream from the bulkhead to the gauge point should be not less than four times the maximum head to be run over the crest, or the head may be taken at the wall of the weir box at either end of the bulkhead. A staff gauge, having a graduated scale on which the zero is at the same elevation as the weir crest, is usually fixed to the inside face of the weir box in a vertical position at the gauge point. For more accurate readings of the head a stilling well such as is shown in Figure 7 may be used.

Where a simple bulkhead is placed across the channel, a stake or post may be driven into the bed of the weir pond, until its top is level with the crest of the weir. The depth of the water over this post will be the head on the crest. This post should be far enough back to be outside of the effect of the drawdown, and where it can be easily reached from the bank of the channel.

To determine the rate of discharge over the weir, observe the depth of water on the weir crest in feet or inches and refer to Table 2, 3, or 4, depending on the type of weir. These tables are applicable only to weirs installed in the manner previously described.

TABLE 2.—*Discharge table for rectangular weirs with complete contractions computed from the formula* $Q=3.247LH^{1.48}-\left(\frac{0.566L^{1.6}}{1+2L^{1.8}}\right)H^{1.9}$

Head, H [1]		Discharge, Q, for crest lengths, L, of—					Head, H		Discharge, Q, for crest lengths, L, of—				
		1 foot	1.5 feet	2 feet	3 feet	4 feet			1 foot	1.5 feet	2 feet	3 feet	4 feet
Feet	*Inches*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet*	*Inches*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
0.10	1 3/16	0.11	0.16	0.22	0.33	0.44	0.75	9	2.01	3.05	4.10	6.21	8.33
.11	1 5/16	.12	.18	.25	.37	.50	.76	9 1/8	2.05	3.11	4.18	6.33	8.49
.12	1 7/16	.14	.20	.28	.42	.57	.77	9 1/4	2.09	3.17	4.26	6.45	8.66
.13	1 9/16	.15	.22	.32	.47	.64	.78	9 3/8	2.13	3.23	4.34	6.58	8.82
.14	1 11/16	.17	.25	.35	.53	.71	.79	9 1/2	2.17	3.29	4.42	6.70	8.99
.15	1 13/16	.19	.28	.39	.58	.79	.80	9 5/8	2.21	3.35	4.51	6.83	9.16
.16	1 15/16	.21	.31	.43	.64	.86	.81	9 3/4	2.25	3.41	4.59	6.95	9.33
.17	2 1/16	.23	.34	.47	.70	.95	.82	9 13/16	2.29	3.47	4.67	7.08	9.50
.18	2 3/16	.25	.37	.51	.76	1.03	.83	9 15/16	2.33	3.54	4.75	7.21	9.67
.19	2 1/4	.27	.40	.55	.83	1.11	.84	10 1/16	2.37	3.60	4.84	7.33	9.84
.20	2 3/8	.29	.44	.59	.89	1.19	.85	10 3/16	2.41	3.66	4.92	7.46	10.0
.21	2 1/2	.31	.47	.63	.95	1.28	.86	10 5/16	2.46	3.72	5.01	7.59	10.2
.22	2 5/8	.34	.50	.68	1.02	1.37	.87	10 7/16	2.50	3.79	5.10	7.72	10.4
.23	2 3/4	.36	.54	.72	1.09	1.46	.88	10 9/16	2.54	3.85	5.18	7.85	10.5
.24	2 7/8	.38	.57	.77	1.16	1.55	.89	10 11/16	2.58	3.92	5.27	7.99	10.7
.25	3	.40	.61	.82	1.23	1.65	.90	10 13/16	2.62	3.98	5.35	8.12	10.9
.26	3 1/8	.43	.65	.86	1.31	1.75	.91	10 15/16	2.67	4.05	5.44	8.25	11.1
.27	3 1/4	.45	.68	.91	1.38	1.85	.92	11 1/16	2.71	4.11	5.53	8.38	11.2
.28	3 3/8	.48	.72	.96	1.46	1.95	.93	11 3/16	2.75	4.18	5.62	8.52	11.4
.29	3 1/2	.50	.76	1.02	1.53	2.05	.94	11 1/4	2.79	4.24	5.71	8.65	11.6
.30	3 5/8	.53	.80	1.07	1.61	2.16	.95	11 3/8	2.84	4.31	5.80	8.79	11.8
.31	3 3/4	.55	.84	1.12	1.69	2.26	.96	11 1/2	2.88	4.37	5.89	8.93	12.0
.32	3 13/16	.58	.88	1.18	1.77	2.37	.97	11 5/8	2.93	4.44	5.98	9.06	12.2
.33	3 15/16	.61	.92	1.23	1.86	2.48	.98	11 3/4	2.97	4.51	6.07	9.20	12.3
.34	4 1/16	.63	.96	1.28	1.94	2.60	.99	11 7/8	3.01	4.57	6.15	9.34	12.5
.35	4 3/16	.66	1.00	1.34	2.02	2.71	1.00	12	3.06	4.64	6.25	9.48	12.7
.36	4 5/16	.69	1.04	1.40	2.11	2.82	1.01	12 1/8	-------	4.71	6.34	9.62	12.9
.37	4 7/16	.72	1.08	1.45	2.20	2.94	1.02	12 1/4	-------	4.78	6.43	9.76	13.1
.38	4 9/16	.74	1.13	1.51	2.28	3.06	1.03	12 3/8	-------	4.85	6.52	9.90	13.3
.39	4 11/16	.77	1.17	1.57	2.37	3.18	1.04	12 1/2	-------	4.92	6.62	10.0	13.5
.40	4 13/16	.80	1.21	1.63	2.46	3.30	1.05	12 5/8	-------	4.98	6.71	10.2	13.7
.41	4 15/16	.83	1.26	1.69	2.55	3.42	1.06	12 3/4	-------	5.05	6.80	10.3	13.8
.42	5 1/16	.86	1.30	1.75	2.65	3.54	1.07	12 13/16	-------	5.12	6.90	10.5	14.0
.43	5 3/16	.89	1.35	1.81	2.74	3.67	1.08	12 15/16	-------	5.20	6.99	10.6	14.2
.44	5 1/4	.92	1.40	1.88	2.83	3.80	1.09	13 1/16	-------	5.26	7.09	10.8	14.4
.45	5 3/8	.96	1.44	1.94	2.93	3.93	1.10	13 3/16	-------	5.34	7.19	10.9	14.6
.46	5 1/2	.99	1.49	2.00	3.03	4.05	1.11	13 5/16	-------	5.41	7.28	11.0	14.8
.47	5 5/8	1.02	1.54	2.07	3.12	4.18	1.12	13 7/16	-------	5.48	7.38	11.2	15.0
.48	5 3/4	1.05	1.59	2.13	3.22	4.32	1.13	13 9/16	-------	5.55	7.47	11.3	15.2
.49	5 7/8	1.08	1.64	2.20	3.32	4.45	1.14	13 11/16	-------	5.62	7.57	11.5	15.4
.50	6	1.11	1.68	2.26	3.42	4.58	1.15	13 13/16	-------	5.69	7.66	11.6	15.6
.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.16	13 15/16	-------	5.77	7.76	11.8	15.8
.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.17	14 1/16	-------	5.84	7.86	11.9	16.0
.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.18	14 3/16	-------	5.91	7.96	12.1	16.2
.54	6 1/2	1.25	1.89	2.53	3.83	5.13	1.19	14 1/4	-------	5.98	8.06	12.2	16.4
.55	6 5/8	1.28	1.94	2.60	3.94	5.27	1.20	14 3/8	-------	6.06	8.16	12.4	16.6
.56	6 3/4	1.31	1.99	2.67	4.04	5.42	1.21	14 1/2	-------	6.13	8.26	12.5	16.8
.57	6 13/16	1.35	2.04	2.74	4.15	5.56	1.22	14 5/8	-------	6.20	8.35	12.7	17.0
.58	6 15/16	1.38	2.09	2.81	4.26	5.70	1.23	14 3/4	-------	6.28	8.46	12.8	17.2
.59	7 1/16	1.42	2.15	2.88	4.36	5.85	1.24	14 7/8	-------	6.35	8.56	13.0	17.4
.60	7 3/16	1.45	2.20	2.96	4.47	6.00	1.25	15	-------	6.43	8.66	13.1	17.6
.61	7 5/16	1.49	2.25	3.03	4.59	6.14	1.26	15 1/8	-------	-------	-------	13.3	17.9
.62	7 7/16	1.52	2.31	3.10	4.69	6.29	1.27	15 1/4	-------	-------	-------	13.4	18.1
.63	7 9/16	1.56	2.36	3.17	4.81	6.44	1.28	15 3/8	-------	-------	-------	13.6	18.3
.64	7 11/16	1.60	2.42	3.25	4.92	6.59	1.29	15 1/2	-------	-------	-------	13.8	18.5
.65	7 13/16	1.63	2.47	3.32	5.03	6.75	1.30	15 5/8	-------	-------	-------	13.9	18.7
.66	7 15/16	1.67	2.53	3.40	5.15	6.90	1.31	15 3/4	-------	-------	-------	14.1	18.9
.67	8 1/16	1.71	2.59	3.47	5.26	7.05	1.32	15 13/16	-------	-------	-------	14.2	19.1
.68	8 3/16	1.74	2.64	3.56	5.38	7.21	1.33	15 15/16	-------	-------	-------	14.4	19.3
.69	8 1/4	1.78	2.70	3.63	5.49	7.36	1.34	16 1/16	-------	-------	-------	14.6	19.6
.70	8 3/8	1.82	2.76	3.71	5.61	7.52	1.35	16 3/16	-------	-------	-------	14.7	19.8
.71	8 1/2	1.86	2.81	3.78	5.73	7.68	1.36	16 5/16	-------	-------	-------	14.9	20.0
.72	8 5/8	1.90	2.87	3.86	5.85	7.84	1.37	16 7/16	-------	-------	-------	15.0	20.2
.73	8 3/4	1.93	2.93	3.94	5.97	8.00	1.38	16 9/16	-------	-------	-------	15.2	20.4
.74	8 7/8	1.97	2.99	4.02	6.09	8.17	1.39	16 11/16	-------	-------	-------	15.4	20.6

[1] Values of discharge for heads up to 0.20 foot do not follow the formula but are taken directly from the calibration curve.

TABLE 3.—*Discharge table for Cipolletti weirs with complete contractions computed from the formula* $Q=3.247LH^{1.48}-\left(\frac{0.566L^{1.8}}{1+2L^{1.8}}\right)H^{1.9}+0.609H^{2.5}$

Head, H [1]		Discharge, Q, for crest lengths, L, of—					Head, H		Discharge, Q, for crest lengths, L, of—				
		1 foot	1.5 feet	2 feet	3 feet	4 feet			1 foot	1.5 feet	2 feet	3 feet	4 feet
Feet	*Inches*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet*	*Inches*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
0.10	1 3/16	0.11	0.16	0.23	0.33	0.44	0.75	9	2.31	3.35	4.40	6.51	8.62
.11	1 5/16	.12	.18	.26	.38	.50	.76	9 1/8	2.36	3.42	4.49	6.64	8.80
.12	1 7/16	.14	.21	.29	.43	.57	.77	9 1/4	2.41	3.49	4.58	6.77	8.97
.13	1 9/16	.16	.24	.32	.48	.64	.78	9 3/8	2.46	3.56	4.67	6.90	9.15
.14	1 11/16	.17	.26	.36	.54	.71	.79	9 1/2	2.51	3.63	4.76	7.04	9.33
.15	1 13/16	.19	.29	.39	.59	.79	.80	9 5/8	2.56	3.70	4.85	7.18	9.51
.15	1 15/16	.21	.32	.43	.65	.87	.81	9 3/4	2.61	3.77	4.95	7.31	9.69
.17	2 1/16	.23	.36	.47	.71	.96	.82	9 13/16	2.66	3.84	5.04	7.45	9.87
.18	2 3/16	.25	.39	.51	.77	1.04	.83	9 15/16	2.71	3.92	5.14	7.59	10.0
.19	2 1/4	.28	.42	.56	.83	1.12	.84	10 1/16	2.77	3.99	5.23	7.73	10.2
.20	2 3/8	.30	.45	.60	.90	1.20	.85	10 3/16	2.82	4.07	5.33	7.87	10.4
.21	2 1/2	.32	.48	.64	.97	1.29	.86	10 5/16	2.87	4.14	5.43	8.01	10.6
.22	2 5/8	.35	.52	.69	1.04	1.38	.87	10 7/16	2.93	4.22	5.52	8.15	10.8
.23	2 3/4	.37	.55	.74	1.11	1.47	.88	10 9/16	2.98	4.29	5.62	8.30	11.0
.24	2 7/8	.39	.59	.79	1.18	1.57	.89	10 11/16	3.04	4.37	5.72	8.44	11.2
.25	3	.42	.63	.84	1.25	1.67	.90	10 13/16	3.09	4.45	5.82	8.59	11.4
.26	3 1/8	.45	.67	.89	1.33	1.77	.91	10 15/16	3.15	4.53	5.92	8.73	11.6
.27	3 1/4	.47	.70	.94	1.40	1.87	.92	11 1/16	3.20	4.60	6.02	8.88	11.7
.28	3 3/8	.50	.74	.99	1.48	1.97	.93	11 3/16	3.26	4.68	6.13	9.03	11.9
.29	3 1/2	.53	.79	1.04	1.56	2.08	.94	11 1/4	3.32	4.76	6.23	9.17	12.1
.30	3 5/8	.56	.83	1.10	1.64	2.19	.95	11 3/8	3.37	4.84	6.33	9.32	12.3
.31	3 3/4	.59	.87	1.15	1.73	2.30	.96	11 1/2	3.43	4.92	6.44	9.48	12.5
.32	3 13/16	.61	.91	1.21	1.80	2.41	.97	11 5/8	3.49	5.00	6.55	9.62	12.7
.33	3 15/16	.64	.95	1.27	1.89	2.52	.98	11 3/4	3.55	5.09	6.64	9.78	12.9
.34	4 1/16	.67	1.00	1.32	1.98	2.64	.99	11 7/8	3.61	5.17	6.75	9.93	13.1
.35	4 3/16	.70	1.04	1.38	2.07	2.75	1.00	12	3.67	5.25	6.86	10.1	13.3
.36	4 5/16	.73	1.09	1.44	2.16	2.87	1.01	12 1/8	-------	5.33	6.96	10.2	13.5
.37	4 7/16	.77	1.13	1.50	2.25	2.99	1.02	12 1/4	-------	5.42	7.07	10.4	13.7
.38	4 9/16	.80	1.18	1.57	2.34	3.11	1.03	12 3/8	-------	5.50	7.18	10.6	13.9
.39	4 11/16	.83	1.23	1.63	2.43	3.24	1.04	12 1/2	-------	5.59	7.29	10.7	14.2
.40	4 13/16	.87	1.28	1.69	2.53	3.36	1.05	12 5/8	-------	5.67	7.40	10.9	14.4
.41	4 15/16	.90	1.32	1.76	2.62	3.49	1.06	12 3/4	-------	5.76	7.51	11.0	14.6
.42	5 1/16	.93	1.37	1.82	2.72	3.61	1.07	12 13/16	-------	5.84	7.62	11.2	14.8
.43	5 3/16	.97	1.42	1.89	2.81	3.74	1.08	12 15/16	-------	5.93	7.73	11.4	15.0
.44	5 1/4	1.00	1.47	1.95	2.91	3.87	1.09	13 1/16	-------	6.02	7.84	11.5	15.2
.45	5 3/8	1.04	1.53	2.02	3.01	4.01	1.10	13 3/16	-------	6.11	7.96	11.7	15.4
.46	5 1/2	1.07	1.58	2.09	3.11	4.14	1.11	13 5/16	-------	6.20	8.07	11.8	15.6
.47	5 5/8	1.11	1.63	2.16	3.21	4.28	1.12	13 7/16	-------	6.29	8.18	12.0	15.8
.48	5 3/4	1.15	1.68	2.23	3.32	4.41	1.13	13 9/16	-------	6.37	8.29	12.2	16.0
.49	5 7/8	1.18	1.74	2.30	3.42	4.55	1.14	13 11/16	-------	6.46	8.41	12.3	16.3
.50	6	1.22	1.79	2.37	3.53	4.69	1.15	13 13/16	-------	6.56	8.53	12.5	16.5
.51	6 1/8	1.26	1.85	2.44	3.64	4.83	1.16	13 15/16	-------	6.65	8.65	12.7	16.7
.52	6 1/4	1.30	1.90	2.51	3.74	4.97	1.17	14 1/16	-------	6.74	8.76	12.8	16.9
.53	6 3/8	1.34	1.96	2.59	3.85	5.12	1.18	14 3/16	-------	6.83	8.88	13.0	17.2
.54	6 1/2	1.38	2.02	2.66	3.96	5.26	1.19	14 1/4	-------	6.93	9.00	13.2	17.4
.55	6 5/8	1.42	2.07	2.74	4.07	5.41	1.20	14 3/8	-------	7.02	9.12	13.4	17.6
.56	6 3/4	1.46	2.13	2.81	4.18	5.56	1.21	14 1/2	-------	7.11	9.24	13.5	17.8
.57	6 13/16	1.50	2.19	2.89	4.30	5.71	1.22	14 5/8	-------	7.20	9.36	13.7	18.0
.58	6 15/16	1.54	2.25	2.97	4.41	5.86	1.23	14 3/4	-------	7.30	9.48	13.9	18.3
.59	7 1/16	1.58	2.31	3.05	4.53	6.01	1.24	14 7/8	-------	7.40	9.60	14.0	18.5
.60	7 3/16	1.62	2.37	3.13	4.64	6.17	1.25	15	-------	7.49	9.72	14.2	18.7
.61	7 5/16	1.67	2.43	3.20	4.76	6.32	1.26	15 1/8	-------	-------	-------	14.4	19.0
.62	7 7/16	1.71	2.49	3.28	4.88	6.47	1.27	15 1/4	-------	-------	-------	14.6	19.2
.63	7 9/16	1.75	2.55	3.37	5.00	6.63	1.28	15 3/8	-------	-------	-------	14.7	19.4
.64	7 11/16	1.80	2.62	3.45	5.12	6.79	1.29	15 1/2	-------	-------	-------	14.9	19.6
.65	7 13/16	1.84	2.68	3.53	5.24	6.95	1.30	15 5/8	-------	-------	-------	15.1	19.9
.66	7 15/16	1.89	2.75	3.61	5.36	7.11	1.31	15 3/4	-------	-------	-------	15.3	20.1
.67	8 1/16	1.93	2.81	3.70	5.48	7.28	1.32	15 13/16	-------	-------	-------	15.5	20.3
.68	8 3/16	1.98	2.87	3.79	5.61	7.44	1.33	15 15/16	-------	-------	-------	15.6	20.6
.69	8 1/4	2.02	2.94	3.87	5.73	7.61	1.34	16 1/16	-------	-------	-------	15.8	20.8
.70	8 3/8	2.07	3.01	3.95	5.86	7.77	1.35	16 3/16	-------	-------	-------	16.0	21.1
.71	8 1/2	2.12	3.07	4.04	5.99	7.94	1.36	16 5/16	-------	-------	-------	16.2	21.3
.72	8 5/8	2.16	3.14	4.13	6.12	8.11	1.37	16 7/16	-------	-------	-------	16.4	21.5
.73	8 3/4	2.21	3.21	4.22	6.24	8.28	1.38	16 9/16	-------	-------	-------	16.6	21.8
.74	8 7/8	2.26	3.28	4.31	6.38	8.45	1.39	16 11/16	-------	-------	-------	16.8	22.0

[1] Values of discharge for heads up to 0.20 foot do not follow the formula but are taken directly from the calibration curve.

TABLE 4.—*Discharge table for 90° triangular-notch weir with complete contractions computed from the formula* $Q=2.49H^{2.48}$

Head, H		Discharge, Q	Head, H		Discharge, Q	Head, H		Discharge, Q
Feet	*Inches*	*Sec.-ft.*	*Feet*	*Inches*	*Sec.-ft.*	*Feet*	*Inches*	*Sec.-ft.*
0.20	2 3/8	0.046	0.55	6 5/8	0.564	0.90	10 13/16	1.92
.21	2 1/2	.052	.56	6 3/4	.590	.91	10 15/16	1.97
.22	2 5/8	.058	.57	6 13/16	.617	.92	11 1/16	2.02
.23	2 3/4	.065	.58	6 15/16	.644	.93	11 3/16	2.08
.24	2 7/8	.072	.59	7 1/16	.672	.94	11 1/4	2.13
.25	3	.080	.60	7 3/16	.700	.95	11 3/8	2.19
.26	3 1/8	.088	.61	7 5/16	.730	.96	11 1/2	2.25
.27	3 1/4	.096	.62	7 7/16	.760	.97	11 5/8	2.31
.28	3 3/8	.106	.63	7 9/16	.790	.98	11 3/4	2.37
.29	3 1/2	.115	.64	7 11/16	.822	.99	11 7/8	2.43
.30	3 5/8	.125	.65	7 13/16	.854	1.00	12	2.49
.31	3 3/4	.136	.66	7 15/16	.887	1.01	12 1/8	2.55
.32	3 13/16	.147	.67	8 1/16	.921	1.02	12 1/4	2.61
.33	3 15/16	.159	.68	8 3/16	.955	1.03	12 3/8	2.68
.34	4 1/16	.171	.69	8 1/4	.991	1.04	12 1/2	2.74
35	4 3/16	.184	.70	8 3/8	1.03	1.05	12 5/8	2.81
.36	4 5/16	.197	.71	8 1/2	1.06	1.06	12 3/4	2.87
.37	4 7/16	.211	.72	8 5/8	1.10	1.07	12 13/16	2.94
.38	4 9/16	.225	.73	8 3/4	1.14	1.08	12 15/16	3.01
.39	4 11/16	.240	.74	8 7/8	1.18	1.09	13 1/16	3.08
.40	4 13/16	.256	.75	9	1.22	1.10	13 3/16	3.15
.41	4 15/16	.272	.76	9 1/8	1.26	1.11	13 5/16	3.22
.42	5 1/16	.289	.77	9 1/4	1.30	1.12	13 7/16	3.30
.43	5 3/16	.306	.78	9 3/8	1.34	1.13	13 9/16	3.37
.44	5 1/4	.324	.79	9 1/2	1.39	1.14	13 11/16	3.44
.45	5 3/8	.343	.80	9 5/8	1.43	1.15	13 13/16	3.52
.46	5 1/2	.362	.81	9 3/4	1.48	1.16	13 15/16	3.59
.47	5 5/8	.382	.82	9 13/16	1.52	1.17	14 1/16	3.67
.48	5 3/4	.403	.83	9 15/16	1.57	1.18	14 3/16	3.75
.49	5 7/8	.424	.84	10 1/16	1.61	1.19	14 1/4	3.83
.50	6	.445	.85	10 3/16	1.66	1.20	14 3/8	3.91
.51	6 1/8	.468	.86	10 5/16	1.71	1.21	14 1/2	3.99
.52	6 1/4	.491	.87	10 7/16	1.76	1.22	14 5/8	4.07
.53	6 3/8	.515	.88	10 9/16	1.81	1.23	14 3/4	4.16
.54	6 1/2	.539	.89	10 11/16	1.86	1.24	14 7/8	4.24
						1.25	15	4.33

LIMITATIONS OF WEIRS

The weir, when properly set and maintained, is perhaps the most accurate means of measuring flowing water, but when operated under field conditions, such as are found in irrigation practice, it is often unreliable. In order that a weir shall continue to measure water accurately the side and bottom contraction distances must remain unchanged. Water passing through earth channels carries more or less sand and sediment which accumulate in the weir box or pond, upstream from the weir bulkhead. This filling eventually destroys the standard bottom-contraction distance, thus increasing the velocity of the water's approach. The error thus caused in the rate of discharge is slight at first, but when the surface of the deposit approaches the level of the crest, the increase in discharge over that indicated by the head is appreciable.

Wooden crest and sides for a weir notch are not desirable, as their natural wear and deterioration dull the edge of the notch and result in increased discharge. A weir box built to provide proper side and bottom contraction distances requires a large amount of material.

In many cases the weir can not be used because of insufficient grade or available head. If the surface of the water below the weir rises

above the crest level, the rate of flow is reduced. Moreover, a weir may easily be altered in order to obtain an unfair advantage either way.

PARSHALL MEASURING FLUME

The Parshall measuring flume consists of a converging section, a throat, and a diverging section, the floor of the throat section being inclined as shown in Figure 2, section L–L. Numerous field experiments have proved this device to be accurate and dependable.

The discharge through the Parshall flume is called free flow when the elevation of the water surface downstream from the throat of

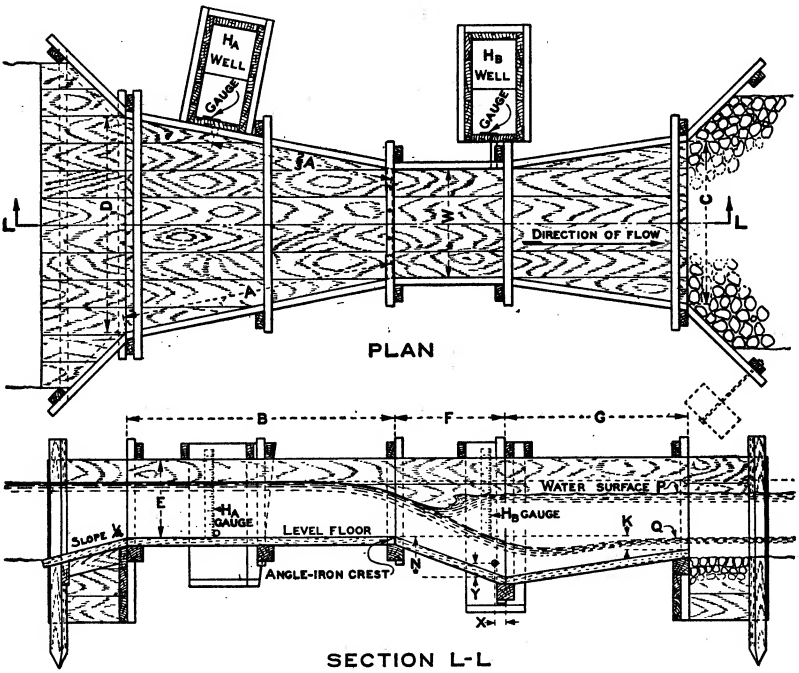

FIGURE 2.—Plan and elevation of the Parshall measuring flume

the flume is not sufficient to cause the flow to be retarded by the backwater. When the surface downstream is high enough to affect the flow, the critical point of submergence has been reached and the condition of submerged flow begins. At first the discharge is only slightly decreased, but as the degree of submergence increases a greater reduction in the rate of flow results; when the downstream and upstream water surfaces have the same elevation the submergence is said to be complete.

Two advantages of the Parshall measuring flume are that its accuracy is not affected by a high degree of submergence and the high velocity of the water in the converging section prevents accumulation of sand and silt.

Table 5 gives the required dimensions for various sizes of the Parshall measuring flume, the letters referring to Figure 2. The size of flume (W) is taken as the horizontal distance between the

vertical, parallel walls of the throat section, and is identical with the crest, which is the line where the level floor of the converging section joins the inclined floor of the throat section. The floor of the converging section is level both transversely and longitudinally. For flumes ranging in size from 1 foot to 4 feet, the lengths of the throat and diverging sections are uniformly 2 feet and 3 feet, respectively. The floor of the throat section slopes downward from the crest 9 inches in 2 feet of length. The floor of the diverging section in the 1-foot to 4-foot sizes slopes upward 6 inches in 3 feet; thus the elevation of the floor of the downstream end of the flume is 3 inches lower than the crest. The length of the side wall of the converging section (fig. 2, A) has been arbitrarily taken as $\frac{W}{2}+4$, which determines the axial length (B) as given in Table 5 for the 1 to 4 foot flumes. The smaller flumes, 0.25, 0.50, and 0.75 foot, depart somewhat from the ratios of dimensions applicable to the larger flumes.

TABLE 5.—*Dimensions and capacities of the Parshall measuring flume, for various crest lengths*

(Letters refer to Figure 2)

W	A	$\frac{2}{3}$ A	B	C	D	E	F	G	K	N	X	Y	Free-flow capacity	
													Maximum	Minimum
Feet	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	*In.*	*Sec. ft.*	*Sec. ft.*
0.25	1 6⅜	1 ¼	1 6	7	10⅜16	1 3	½	1	1	2¼	1	1½	1.2	0.03
.50	2 7⅛16	1 4⅝16	2	1 3½	1 3½	1 6	1	2	3	4½	2	3	2.9	.05
.75	2 10⅝	1 11⅛	2 10	1 3	1 10⅝	2	1	1½	3	4½	2	3	5.7	.1
1	4 6	3	4 4⅞	2	2 9¼	3	2	3	3	9	2	3	16	.4
2	5	3 4	4 10⅞	3	3 11½	3	2	3	3	9	2	3	33	.7
3	5 6	3 8	5 4¾	4	5 1⅞	3	2	3	3	9	2	3	50	1.0
4	6	4	5 10⅝	5	6 4¼	3	2	3	3	9	2	3	68	1.3

The rate of flow is determined by the head or depth of water at H_A (fig. 2) in case a free-flow condition exists, and at both H_A and H_B in the case of submerged flow. The upper head (H_A) is observed at a point whose distance from the end of the crest is two-thirds of the length of the side wall of the converging section. (Fig. 2, $\frac{2}{3}$ A.) The lower head (H_B) is observed near the downstream end of the throat section. Both gauges H_A and H_B should be set with the zeros of the scales at the elevation of the crest of the flume.

FREE FLOW

Free flow is that condition under which the rate of discharge is dependent solely upon the length of the crest and the depth at the gauge point, H_A, in the converging section. Because of the ability of the Parshall measuring flume to withstand a relatively high degree of submergence without reduction in the rate of flow, free-flow discharge is obtained with a rather wide range of backwater conditions downstream from the structure. It has been observed that the stream passing through the throat can assume two different stages of free flow: (1) The water at high velocity moves in a thin

sheet which conforms closely with the dip at the lower end of the throat (indicated by Q in Figure 2), and (2) the backwater raises the water surface to P, causing a ripple or wave to form at or near the downstream end of the throat. For this higher stage (P) there occurs a marked reduction in the velocity of the water as it leaves the lower end of the flume. If the ratio of the H_B gauge to the H_A gauge is 0.7 or less for the 1 to 4 foot flumes, or 0.6 for the 0.25, 0.50, and 0.75 foot flumes, then the rate of discharge may be found by measuring the depth at the H_A gauge and referring to Table 6. The ratio of the H_B gauge to the H_A gauge is found by dividing the depth or head at H_B by the depth as measured at H_A.

Table 6 gives the rates of discharge in second-feet through this flume for sizes of from 0.25 foot to 4 feet. The 0.25-foot flume is intended for the accurate measurements of small flows down to approximate one-thirtieth second-foot as a minimum.

TABLE 6.—*Free flow discharge through Parshall measuring flume*[1]

Head, H_A	Discharge, Q, for throat widths, W, of—							Head, H_A	Discharge, Q, for throat widths, W, of—						
	0.25 foot	0.50 foot	0.75 foot	1 foot	2 feet	3 feet	4 feet		0.25 foot	0.50 foot	0.75 foot	1 foot	2 feet	3 feet	4 feet
Feet	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
0.10	0.028	0.05	0.09	------	------	------	------	0.57	0.415	0.85	1.30	1.70	3.35	4.98	6.59
.11	.033	.06	.10	------	------	------	------	.58	.427	.87	1.33	1.75	3.44	5.11	6.77
.12	.037	.07	.12	------	------	------	------	.59	.438	.89	1.37	1.80	3.53	5.25	6.96
.13	.042	.08	.14	------	------	------	------	.60	.450	.92	1.40	1.84	3.62	5.39	7.15
.14	.047	.09	.15	------	------	------	------	.61	.462	.94	1.44	1.88	3.72	5.53	7.34
.15	.053	.10	.17	------	------	------	------	.62	.474	.97	1.48	1.93	3 81	5 68	7.53
.16	.058	.11	.19	------	------	------	------	.63	.485	.99	1.51	1.98	3.91	5.82	7.72
.17	.064	.12	.20	------	------	------	------	.64	.497	1.02	1.55	2.03	4.01	5.97	7.91
.18	.070	.14	.22	------	------	------	------	.65	.509	1.04	1.59	2.08	4.11	6.12	8.11
.19	.076	.15	.24	------	------	------	------	.66	.522	1.07	1.63	2.13	4.20	6.26	8.31
.20	.082	.16	.26	0.35	0.66	0.97	1.26	.67	.534	1.10	1.66	2.18	4.30	6.41	8.51
.21	.089	.18	.28	.37	.71	1.04	1.36	.68	.546	1.12	1.70	2.23	4.40	6.56	8.71
.22	.095	.19	.30	.40	.77	1.12	1.47	.69	.558	1.15	1.74	2.28	4.50	6.71	8.91
.23	.102	.20	.32	.43	.82	1.20	1.58	.70	.571	1.17	1.78	2.33	4.60	6.86	9.11
.24	.109	.22	.35	.46	.88	1.28	1.68	.71	.584	1.20	1.82	2.38	4.70	7.02	9.32
.25	.117	.23	.37	.49	.93	1.37	1.80	.72	.597	1.23	1.86	2.43	4.81	7.17	9.53
.26	.124	.25	.39	.51	.99	1.46	1.91	.73	.610	1.26	1.90	2.48	4.91	7.33	9.74
.27	.131	.26	.41	.54	1.05	1.55	2.03	.74	.623	1.28	1.94	2.53	5.02	7.49	9.95
.28	.138	.28	.44	.58	1.11	1.64	2.15	.75	------	1.31	1.98	2.58	5.12	7.65	10.2
.29	.146	.29	.46	.61	1.18	1.73	2.27	.76	------	1.34	2.02	2.63	5.23	7.81	10.4
.30	.154	.31	.49	.64	1.24	1.82	2.39	.77	------	1.36	2.06	2.68	5.34	7.97	10.6
.31	.162	.32	.51	.68	1.30	1.92	2.52	.78	------	1.39	2.10	2.74	5.44	8.13	10.8
.32	.170	.34	.54	.71	1.37	2.02	2.65	.79	------	1.42	2.14	2.80	5.55	8.30	11.0
.33	.179	.36	.56	.74	1.44	2.12	2.78	.80	------	1.45	2.18	2.85	5.66	8.46	11.2
.34	.187	.38	.59	.77	1.50	2.22	2.92	.81	------	1.48	2.22	2.90	5.77	8.63	11.5
.35	.196	.39	.62	.80	1.57	2.32	3.06	.82	------	1.50	2.27	2.96	5.88	8.79	11.7
.36	.205	.41	.64	.84	1.64	2.42	3.19	.83	------	1.53	2.31	3.02	6.00	8.96	11.9
.37	.213	.43	.67	.88	1.72	2.53	3.34	.84	------	1.56	2.35	3.07	6.11	9.13	12.2
.38	.222	.45	.70	.92	1.79	2.64	3.48	.85	------	1.59	2.39	3.12	6.22	9.30	12.4
.39	.231	.47	.73	.95	1.86	2.75	3.62	.86	------	1.62	2.44	3.18	6.33	9.48	12.6
.40	.241	.48	.76	.99	1.93	2.86	3.77	.87	------	1.65	2.48	3.24	6.44	9.65	12.8
.41	.250	.50	.78	1.03	2.01	2.97	3.92	.88	------	1.68	2.52	3.29	6.56	9.82	13.1
.42	.260	.52	.81	1.07	2.09	3.08	4.07	.89	------	1.71	2.57	3.35	6.68	10.0	13.3
.43	.269	.54	.84	1.11	2.16	3.20	4.22	.90	------	1.74	2.61	3.41	6.80	10.2	13.6
.44	.279	.56	.87	1.15	2.24	3.32	4.38	.91	------	1.77	2.66	3.46	6.92	10.4	13.8
.45	.289	.58	.90	1.19	2.32	3.44	4.54	.92	------	1.81	2.70	3.52	7.03	10.5	14.0
.46	.299	.61	.94	1.23	2.40	3.56	4.70	.93	------	1.84	2.75	3.58	7.15	10.7	14.3
.47	.309	.63	.97	1.27	2.48	3.68	4.86	.94	------	1.87	2.79	3.64	7.27	10.9	14.5
.48	.319	.65	1.00	1.31	2.57	3.80	5.03	.95	------	1.90	2.84	3.70	7.39	11.1	14.8
.49	.329	.67	1.03	1.35	2.65	3.92	5.20	.96	------	1.93	2.88	3.76	7.51	11.3	15.0
.50	.339	.69	1.06	1.39	2.73	4.05	5.36	.97	------	1.97	2.93	3.82	7.63	11.4	15.2
.51	.350	.71	1.10	1.44	2.82	4.18	5.53	.98	------	2.00	2.98	3.88	7.75	11.6	15.5
.52	.361	.73	1.13	1.48	2.90	4.31	5.70	.99	------	2.03	3.02	3.94	7.88	11.8	15.8
.53	.371	.76	1.16	1.52	2.99	4.44	5.88	1.00	------	2.06	3.07	4.00	8.00	12.0	16.0
.54	.382	.78	1.20	1.57	3.08	4.57	6.05	1.01	------	2.09	3.12	4.06	8.12	12.2	16.2
.55	.393	.80	1.23	1.62	3.17	4.70	6.23	1.02	------	2.12	3.17	4.12	8.25	12.4	16.5
.56	.404	.82	1.26	1.66	3.26	4.84	6.41	1.03	------	2.16	3.21	4.18	8.38	12.6	16.8

[1] Letters, H_A and W, refer to Figure 2. To convert decimal fractions of a foot to inches and fractions, set corresponding units in Table 2.

TABLE 6.—*Free flow discharge through Parshall measuring flume*—Continued.

Head, H_A	Discharge, Q, for throat widths, W, of—							Head, H_A	Discharge, Q, for throat widths, W, of—						
	0.25 foot	0.50 foot	0.75 foot	1 foot	2 feet	3 feet	4 feet		0.25 foot	0.50 foot	0.75 foot	1 foot	2 feet	3 feet	4 feet
Feet	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Feet*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
1.04	------	2.19	3.26	4.25	8.50	12.8	17.0	1.22	------	2.82	4.16	5.41	10.9	16.4	21.9
1.05	------	2.22	3.31	4.31	8.63	13.0	17.3	1.23	------	2.86	4.22	5.48	11.0	16.6	22.2
1.06	------	2.26	3.36	4.37	8.76	13.2	17.5	1.24	------	2.89	4.27	5.55	11.2	16.8	22.5
1.07	------	2.29	3.40	4.43	8.88	13.3	17.8	1.25	------	------	4.32	5.62	11.3	17.0	22.8
1.08	------	2.32	3.45	4.50	9.01	13.5	18.1	1.26	------	------	4.37	5.69	11.4	17.2	23.0
1.09	------	2.36	3.50	4.56	9.14	13.7	18.3	1.27	------	------	4.43	5.76	11.6	17.4	23.3
1.10	------	2.40	3.55	4.62	9.27	13.9	18.6	1.28	------	------	4.48	5.82	11.7	17.7	23.6
1.11	------	2.43	3.60	4.68	9.40	14.1	18.9	1.29	------	------	4.53	5.89	11.9	17.9	23.9
1.12	------	2.46	3.65	4.75	9.54	14.3	19.1	1.30	------	------	4.59	5.96	12.0	18.1	24.2
1.13	------	2.50	3.70	4.82	9.67	14.5	19.4	1.31	------	------	4.64	6.03	12.2	18.3	24.5
1.14	------	2.53	3.75	4.88	9.80	14.7	19.7	1.32	------	------	4.69	6.10	12.3	18.5	24.8
1.15	------	2.57	3.80	4.94	9.94	14.9	19.9	1.33	------	------	4.75	6.18	12.4	18.8	25.1
1.16	------	2.60	3.85	5.01	10.1	15.1	20.2	1.34	------	------	4.80	6.25	12.6	19.0	25.4
1.17	------	2.64	3.90	5.08	10.2	15.3	20.5	1.35	------	------	4.86	6.32	12.7	19.2	25.7
1.18	------	2.68	3.95	5.15	10.3	15.6	20.8	1.36	------	------	4.92	6.39	12.9	19.4	26.0
1.19	------	2.71	4.01	5.21	10.5	15.8	21.0	1.37	------	------	4.97	6.46	13.0	19.6	26.3
1.20	------	2.75	4.06	5.28	10.6	16.0	21.3	1.38	------	------	5.03	6.53	13.2	19.9	26.6
1.21	------	2.78	4.11	5.34	10.8	16.2	21.6	1.39	------	------	5.08	6.60	13.3	20.1	26.9

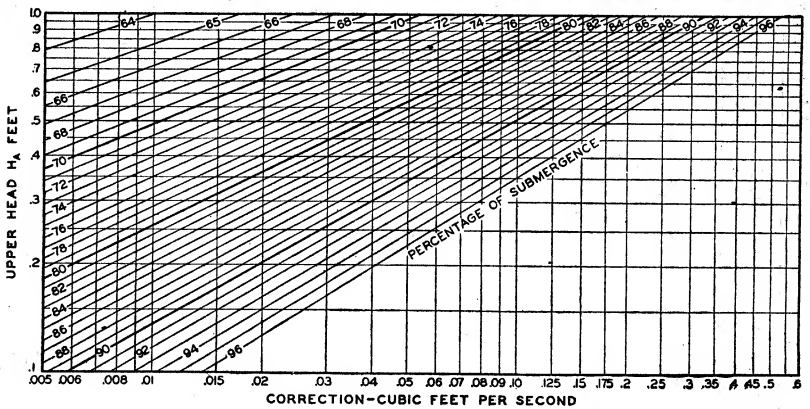

FIGURE 3.—Diagram for computing submerged flow through 0.25-foot Parshall measuring flume

SUBMERGED FLOW

When the ratio of H_B to H_A readings exceeds 0.7 for flumes of 1 foot and larger in size, and 0.6 for those less than 1 foot, it becomes necessary to apply a correction to the free-flow discharge as given in Table 6 in order to determine the rate of the submerged flow. This computed submerged flow is determined by the use of the diagrams shown in Figures 3, 4, 5, and 6. The correction diagram for the 1-foot flume (fig. 6) may be used for larger flumes by multiplying the correction for the 1-foot flume by the factor given below for the particular flume.

Size of flume (W) feet	Multiplier
1	1.0
2	1.8
3	2.4
4	3.1

For example, suppose the head on the H_A gauge of a 3-foot Parshall measuring flume is 1.34 feet, and on the H_B gauge it is 1.21 feet. The ratio $\frac{1.21}{1.34}$ is approximately 0.90 or 90 per cent. At the

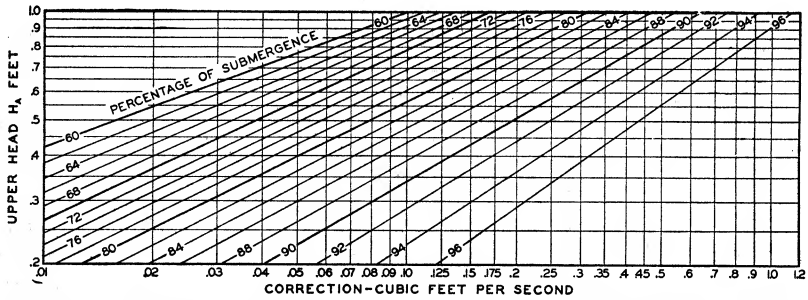

FIGURE 4.—Diagram for computing submerged flow through 0.50-foot Parshall measuring flume

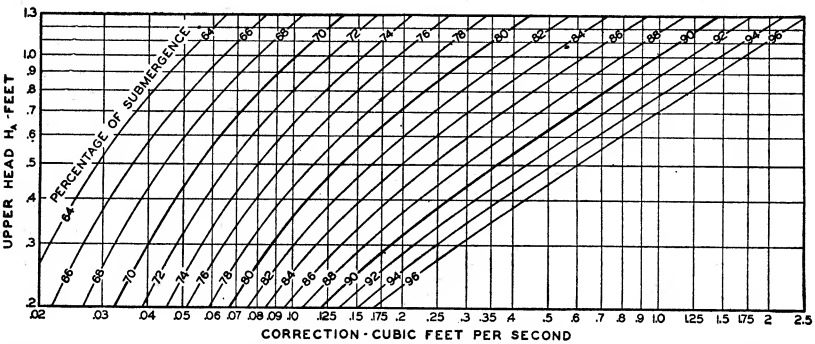

FIGURE 5.—Diagram for computing submerged flow through 0.75-foot Parshall measuring flume

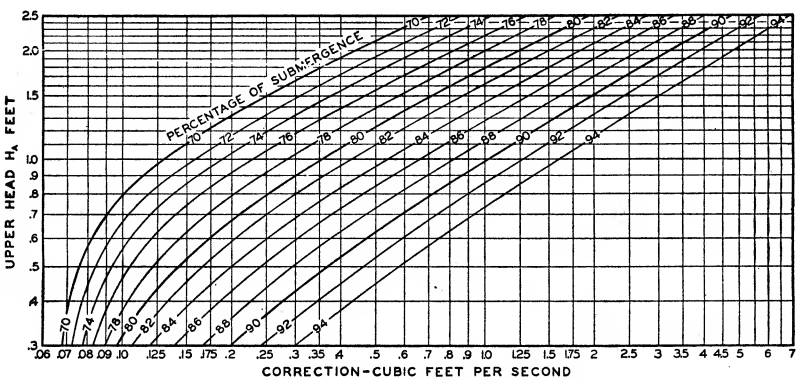

FIGURE 6.—Diagram for computing submerged flow through 1-foot Parshall measuring flume

left margin of the diagram (fig. 6) find the number 1.34 and follow the horizontal line to where it intersects the curve for 90 per cent submergence. Then follow down the vertical line to the bottom of the diagram. This shows the correction for a 1-foot flume to be

about 1.6 second-feet. The correction for the 3-foot flume is found by multiplying 1.6 by 2.4, which gives 3.84 second-feet. From Table 6 it is found that the free-flow discharge for a 3-foot flume with an upper head (H_A) of 1.34 feet is 19.0 second-feet. For submerged flow, therefore, the discharge is 19.0−3.8 or 15.2 second-feet.

Again, for a submerged flow through a 0.5-foot flume, when H_A is 0.72 foot and H_B is 0.59 foot, the ratio is approximately 0.82, and the correction (fig. 4) is 0.18 second-foot. From Table 6 the free-flow discharge for the head (H_A) of 0.72 foot is found to be 1.23 second-feet, and the submerged flow is 1.23−0.18=1.05 second-feet.

SETTING AND SIZE

Successful operation of the Parshall flume depends upon setting the crest at the correct elevation with reference to the bed of the channel. Where sufficient fall is available this setting may be determined with little difficulty, but if the fall is slight care must be taken in fixing the height of the crest so that if possible the degree of submergence shall not exceed the limits of free-flow operation as explained on page 9. In all cases it is necessary to set the crest so that the submergence shall not exceed the practical limitation of about 95 per cent since the flume will not measure accurately if the degree of submergence exceeds this limitation. The elevation of the crest depends upon the quantity of water to be measured and the size of flume to be used.

For example, let it be desired to measure 12 second-feet in a channel of moderate grade, with a depth of water of 1.5 feet at the point where the flume is to be located. This quantity can be measured through several sizes of flume, but from the standpoint of economy the smallest practical size should be selected. Assume that a submergence of 70 per cent shall not be exceeded in order that the flow may be determined by the single gauge H_A. First, consider a 3-foot flume. For a discharge of 12 second-feet (Table 6) it will be noted that the upper head, H_A, is 1 foot. For a submergence of 70 per cent, the ratio of H_B gauge to H_A gauge is 0.7; whence H_B for this condition of flow is found to be 0.7 foot. The loss of head or difference in elevation between the water surfaces upstream and downstream will therefore be approximately 0.3 foot. Since the depth of the water downstream has been assumed to be 1.5 feet, the depth upstream will be greater by 0.3 foot, the loss in head, or 1.8 feet. Now, since the H_A head is 1.0 foot, it is apparent that the level floor of the converging section must be set 0.8 foot above the bed of the channel.

Next, consider a 2-foot flume. Here the upper head (H_A) is 1.30 feet for a free-flow discharge of 12 second-feet. The H_B head for 70 per cent submergence would be 1.30×.70, or 0.91, and the loss of head about 0.4 foot. For this condition, the depth of water upstream from the flume would be about 1.9 feet, and the elevation of the crest would be 0.6 foot above the bed of the channel.

Similarly, for a 1-foot flume to measure 12 second-feet for a 70 per cent submergence, the loss of head is approximately 0.6 foot, and the crest elevation above the bed of the channel would be about 0.1 foot.

It is noted that as the size of flume decreases, the loss of head becomes greater, and the elevation of the floor of the flume above the bed of the channel becomes less. It is usually the better practice to set the flume high rather than low, as a margin of safety in allowing for variations of the water surface downstream from the structure. For the 1-foot flume setting, a loss of head of 0.6 foot may endanger the banks of the upper section of the channel. The 3-foot flume setting, in this case, requires an elevation of the floor above the bed of the channel of 0.8 foot, but the loss of head is the least of the three. It is concluded that the 2-foot flume is the most practical installation to meet the conditions.

In some cases it may be impracticable to set the flume to operate under a free-flow condition, because of insufficient available fall, and it will then become necessary to use both the H_A and H_B gauges, as previously explained. The flume may be placed so as to operate at any desired degree of submergence.

For example, let it be required to use a 3-foot flume to measure 12 second-feet at a submergence of 90 per cent. To arrive at the proper elevation of the crest above the bottom of the channel, it is necessary to refer to Figure 6. For the submerged flow of 12 second-feet, the value of H_A will be somewhat greater than for free flow. Try H_A at 1.2 feet. The free-flow discharge for this head will be found to be 15.96 second-feet. The diagram shows that the correction for 90 per cent submergence for H_A at 1.2 feet is about 1.35 second-feet for a 1-foot flume, and that for the 3-foot flume will be 2.4 times 1.35, or 3.24 second-feet. This amount subtracted from the free flow of 15.96 second-feet will give a submerged flow of 12.72 second-feet. This assumption shows that the value of H_A is too large.

For H_A at 1.16 feet, the computed submerged discharge will be found to be approximately 12.02 second-feet, which is close enough for the purpose. For this condition the loss of head will be 10 per cent of the upper head (H_A), or approximately 0.12 foot. This loss of head added to the depth of water downstream will be 1.62 feet, or the depth of water upstream. Since the value of the H_A head is 1.16 feet, the crest elevation will be the difference, or 0.46 foot.

CONSTRUCTION

The Parshall measuring flume may be built of timber, of concrete, or, in the smaller sizes, of sheet metal. The dimensions for the various sizes of flumes are given in Table 5, in which several columns are headed by capital letters referring to the corresponding dimensions shown in Figure 2. In the construction of this flume it is necessary to build to exact dimensions, especially the converging and throat sections.

For a flume made of lumber, sills and posts should be of ample size, with substantial cross bracing. Figure 2 presents a plan for a framed structure, with 4 by 4 inch sills and posts and common 2-inch plank for the walls and floor. For the larger flumes, 4 by 6 inch posts and sills, with 3-inch surfaced plank will be found to be more satisfactory. Treating the material with appropriate preservatives will lengthen the life of the structure. The bottom wall planks should be placed before the floor is laid. This will prevent the sides

from crowding or bulging in at the bottom and thus materially altering the inside dimensions of the flume. It is recommended that a ⅛-inch space be left between planks when placing the floor and walls, to allow for swelling.

It is essential that the crest be straight and level, and also that the floor of the converging section be level in both directions. An angle-iron crest, as indicated in Figure 2, is strongly recommended. This metal piece, which insures a true and definite edge, should be gained in to set flush with the floor line, and should be firmly held in place by substantial screws with countersunk heads.

Suitable wing walls should be provided at the ends of the structure. Those at the upstream end should be built at angles of about 45° with the axis of the flume. In the smaller flumes the downstream wings may be extended to the sides of the channel at right angles to the flume. It is best to provide a short, inclined floor, with a slope of about 1 to 4, laid flush with the upper end of the floor of the converging section of the flume, as shown in Figure 2. If the material in the bed of the channel is soft, either stone riprap or a wooden apron should be provided at the downstream end of the structure to prevent erosion of the bed and banks.

The construction of this flume in sheet metal for the 0.25, 0.50, 0.75, 1, and 2 foot sizes has proved to be very satisfactory, but the cost somewhat exceeds that of concrete or wood. The metal flume has advantages in that it is portable, can be readily set, and is relatively long-lived. Use of factory-made flumes should assure accuracy of dimensions and uniform construction.

Concrete is preferable for the larger flumes but costs somewhat more than timber. It is durable and is little subject to expansion and contraction, thus insuring uniformity in operation. The method of construction is that of ordinary reinforced-concrete work of a monolithic nature.

STILLING WELLS AND GAUGES

The rate of flow is determined by the water depths in the converging and throat sections of the flume. The stream of water flowing through the device varies slightly in depth, due to the pulsations naturally set up in the moving water. A staff gauge set vertically at the proper point on the inside of the converging wall can be read as the upper head (H_A) with a fair degree of accuracy, while placing such a gauge on the inside of the throat section to observe the lower head (H_B) would be found to be impracticable because of the roughness of the water surface.

For best results, it is recommended that these heads or depths of water be observed in special compartments or stilling wells set just outside of the flume, with small inlet tubes connecting the wells with the flume. The staff gauge is set vertically on the inside face of the stilling well, with the zero or initial point of the graduated scale level with the crest. It is preferable to have this gauge graduated in feet, and tenths and hundredths of a foot, rather than in feet and inches.

The stilling well (fig. 7) should be of sound material, constructed with sides and bottom, and be set vertically, close to the outside of the flume, as shown in Figure 2. At a point two-thirds of the length

of the converging section, back from the crest (Table 5, ⅔ A), insert a tightly fitting 1-inch tube in the H_A stilling well, with the center of the tube about 1½ inches above the floor line. The tube should be long enough to reach through the side wall of the well and should be carefully placed with its end flush with the inside face of the flume wall.

Figure 2 also shows the location of the tube for the throat connection with the H_B stilling well. The light is strong enough in the stilling well for easy reading of the graduations on the staff gauge, and the sloping sides aid in withdrawing the accumulated deposits from the bottom of the well. The bottom of the well should be about 1 foot below the floor line of the flume to catch the deposits of silt without interfering with the passage of water through the inlet tube.

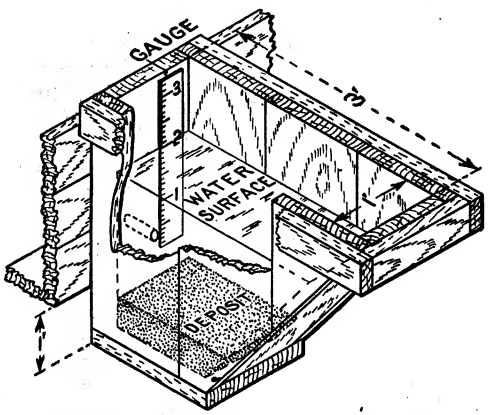

FIGURE 7.—Stilling well with staff gauge

This type of stilling well is also suited to the operation of recording instruments, but where such an instrument is to be used the well must be made about 2 feet wide to allow sufficient room for the float. A Parshall measuring flume with a water-stage recording instrument set over a stilling well is shown on the cover. The ordinary single-stage recorder is adapted to free-flow conditions only. Where the flow is submerged, a special, double-head recording instrument is necessary and here the H_A and H_B, stilling wells may be combined in a single well having a water-tight partition or diaphragm with suitable pipes leading to the proper inlet points in the flume.

VELOCITY OF APPROACH

For some types of measuring devices, such as the weir, it is known that when the stream of water approaches the section of measurement at a greater rate of speed than the standard or correct velocity, the actual discharge is greater than the indicated discharge. This difference is not great for moderate velocities of approach, but if the rate be greatly increased a very marked effect upon the discharge will result.

The velocity of approach, in the case of the weir, is materially affected by deposits of sand and silt upstream from the weir, causing a reduced section through which the water must pass and thus increasing the velocity of its approach. Laboratory tests on a 2-foot Parshall measuring flume show no effect in the indicated rate of discharge for an increase of 85 per cent in the velocity of approach, whereas for a 2-foot rectangular weir with a head of 1.0 foot, it is found that an increase in the velocity of approach of 85 per cent results in an actual rate of flow about 3.4 per cent greater than the indicated flow.

LOSS OF HEAD

The weir, operated under standard conditions of setting, is the most accurate of the more practical devices, but it requires in its operation a relatively large loss of head. Table 7 gives a comparison of the loss of head for the Parshall measuring flume with three types of weirs.

It is to be noted in this comparison that the values given under the headings for the various weirs represent the actual heads or depths on the crest required to give corresponding discharges. In reality, the loss of head is greater than that indicated by the difference in elevation between the downstream water surface and the weir crest. This additional fall is necessary to permit the free passage of air underneath the nappe, or overpouring stream of water, and may be assumed to be from 0.05 to 0.1 foot. This comparison indicates that the loss of head required in the use of weirs is approximately four times as great as that needed for the Parshall flume where the crest length of weir and flume are the same and the flow through the flume is submerged to the free-flow limit.

TABLE 7.—*Comparison of loss of head in feet for equal discharges through Parshall measuring flume, and over weirs*

Discharge	Loss of head of Parshall measuring flume				Loss of head of rectangular weir				Loss of head of Cipolletti weir				Loss of head of 90° triangular-notch weir
	6-inch	1-foot	2-foot	4-foot	6-inch	1-foot	2-foot	4-foot	6-inch	1-foot	2-foot	4-foot	
Sec.-ft.	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
0.10	0.06	------	------	------	0.15	------	------	------	0.15	------	------	------	0.27
.50	.16	0.08	------	------	.46	0.29	0.18	------	.43	0.28	0.18	------	.52
1.00	.25	.12	0.08	------	.74	.46	.29	0.18	.64	.44	.28	0.18	.69
2.00	.41	.19	.12	0.08	1.16	.75	.46	.29	.96	.69	.45	.28	.92
3.00	------	.25	.16	.11	------	.99	.61	.38	------	.88	.58	.37	1.08
5.00	------	.35	.22	.14	------	------	.86	.53	------	------	.82	.52	1.32
7.50	------	.45	.29	.19	------	------	1.13	.70	------	------	1.06	.68	------
10.00	------	.55	.35	.22	------	------	------	.85	------	------	1.27	.83	------
12.50	------	.63	.40	.26	------	------	------	.99	------	------	------	.96	------
15.00	------	------	.45	.29	------	------	------	1.12	------	------	------	1.08	------
20.00	------	------	.54	.35	------	------	------	1.36	------	------	------	1.31	------

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